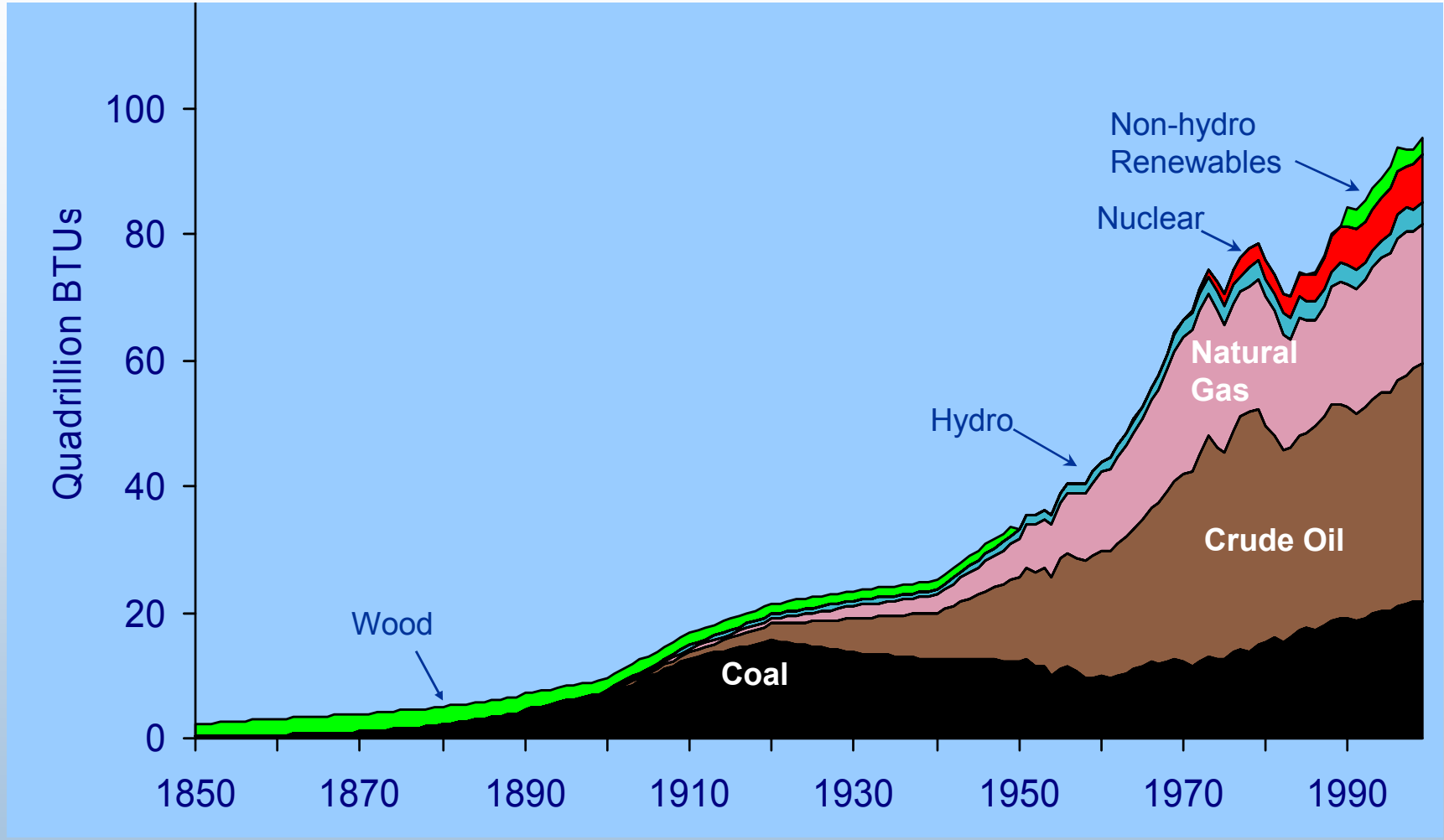
Offshore Wind Technology Overview

Walt Musial
Leader-Offshore Projects
National Renewable Energy Laboratory
walter_musial@nrel.gov

Great Lakes Offshore Wind Energy Gathering
Toledo, OH
April 4, 2006

The U.S. Energy Picture

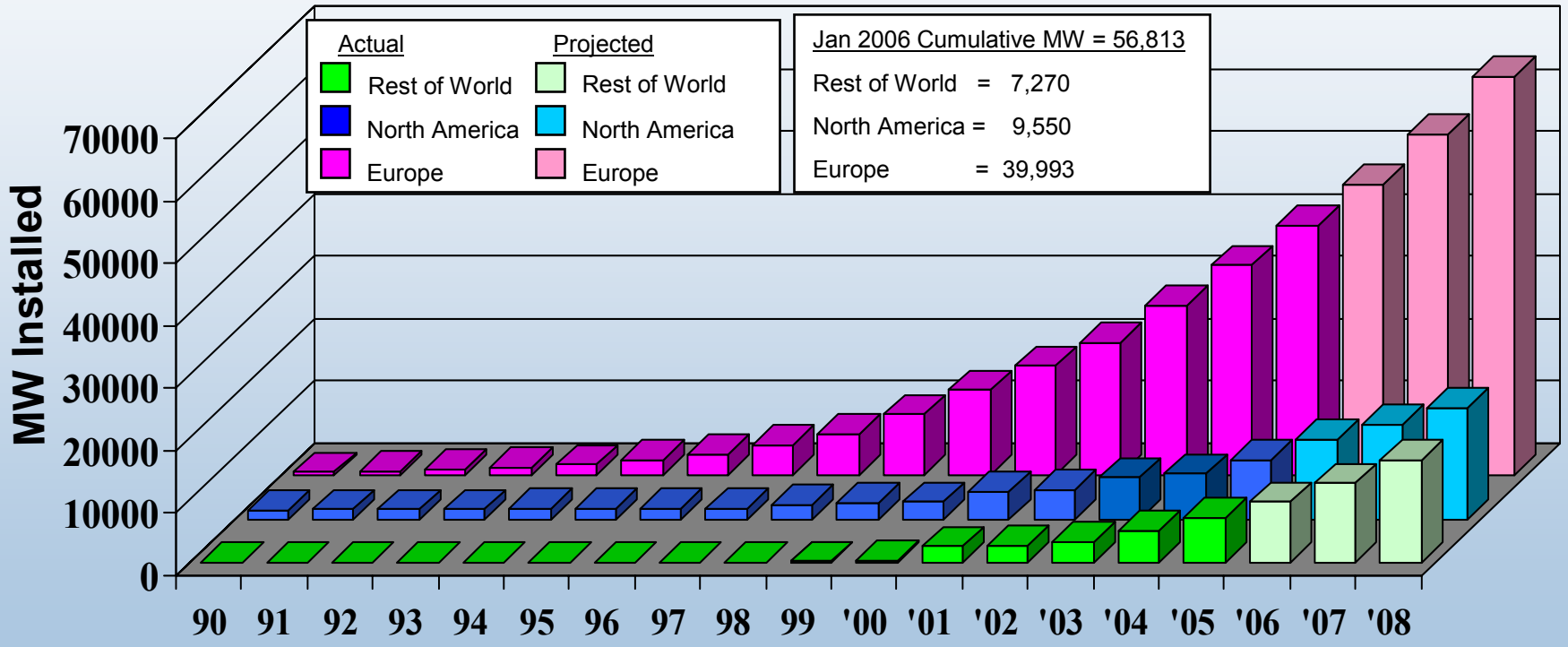
by source - 1850-1999



Source: 1850-1949, Energy Perspectives: A Presentation of Major Energy and Energy-Related Data, U.S. Department of the Interior, 1975; 1950-1996, Annual Energy Review 1996, Table 1.3. Note: Between 1950 and 1990, there was no reporting of non-utility use of renewables. 1997-1999, Annual Energy Review 1999, Table F1b.

Growth of Wind Energy
Cumulative Capacity Worldwide

Less than 1,000 MW is Offshore



Sources: BTM Consult Aps, Sept 2005
Windpower Monthly, January 2006

Predicted Growth of German Wind Energy Markets

WindEnergy

WindEnergy-Study 2008 - Assessment of the Wind Energy Market until 2014
WindEnergy-Studie 2008 - Marktentwicklung der Windindustrie bis zum Jahr 2014

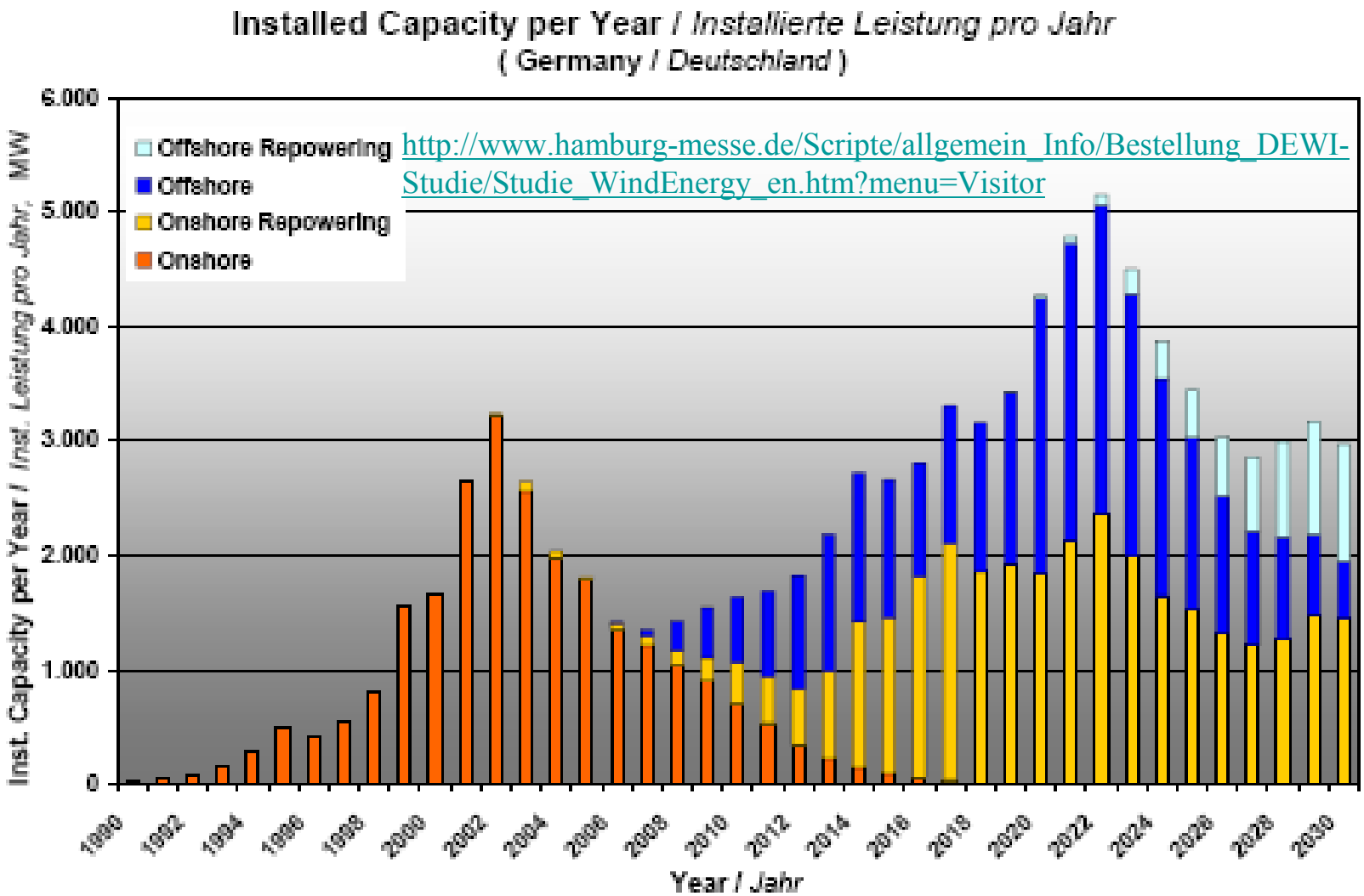


Fig. 3
Abb. 3

Source: WindEnergy-Study 2008

Offshore Wind – U.S. Rationale

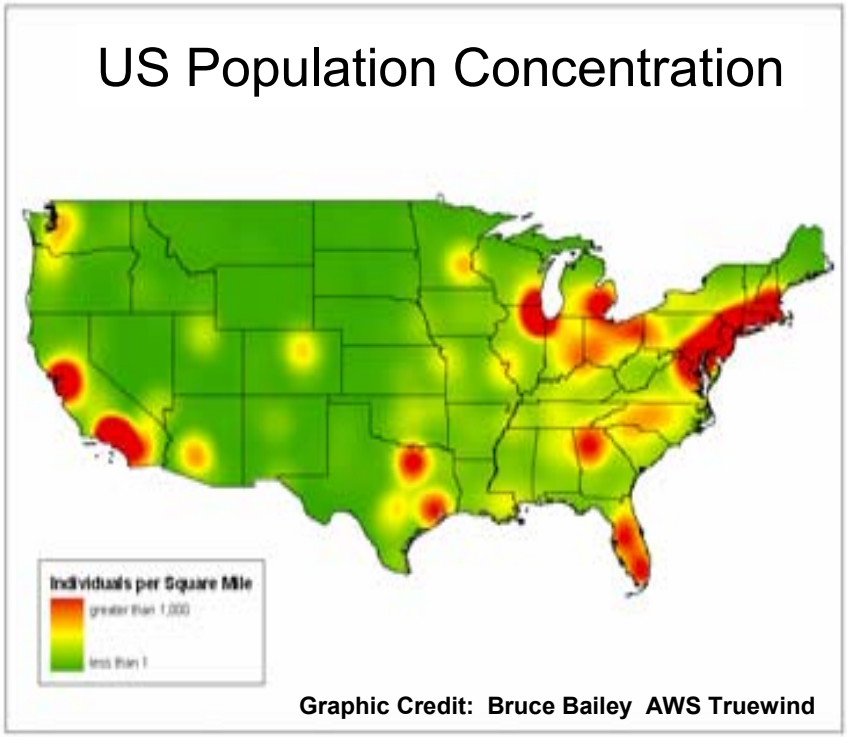
Why Go Offshore?

Windy onshore sites are not close to coastal load centers

The electric utility grid cannot be easily set up for interstate electric transmission

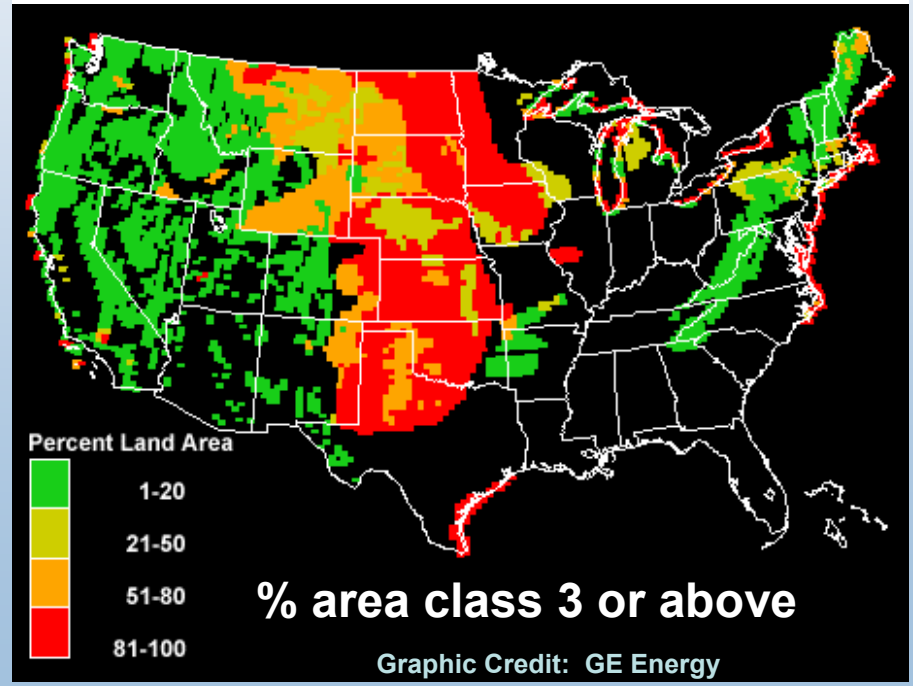
Load centers are close to the offshore wind sites

US Population Concentration



Graphic Credit: Bruce Bailey AWS Truewind

US Wind Resource



Wind Energy Cost Trends

1981: 40 cents/kWh

- **Increased Turbine Size**
- **R&D Advances**
- **Manufacturing Improvements**

2006: 9.5 cents/kWh

- **Multi-megawatt Turbines**
- **High reliability systems**
- **Infrastructure Improvements**

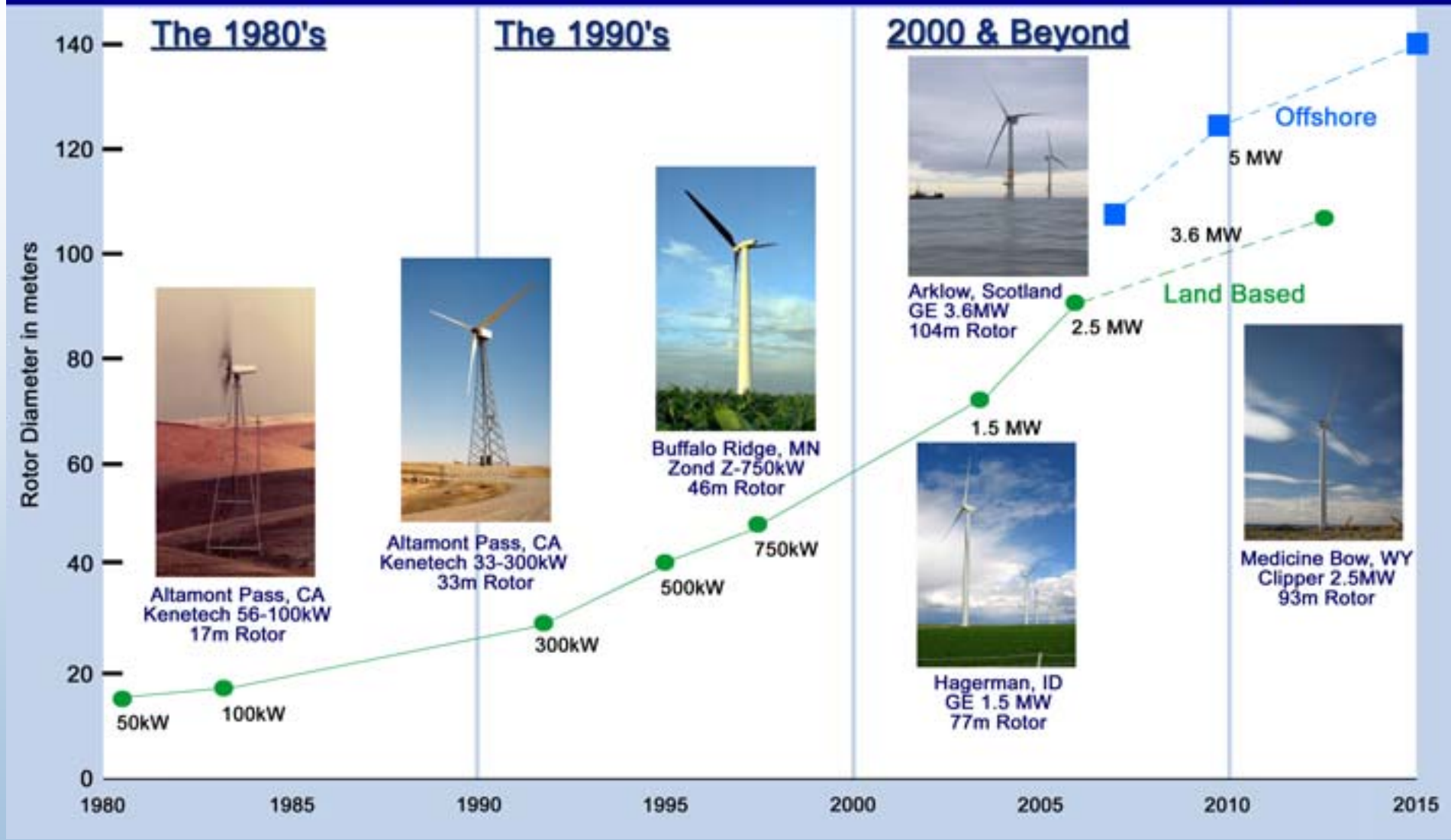
Land-based

Offshore

2006: 3 - 6 cents/kWh with PTC

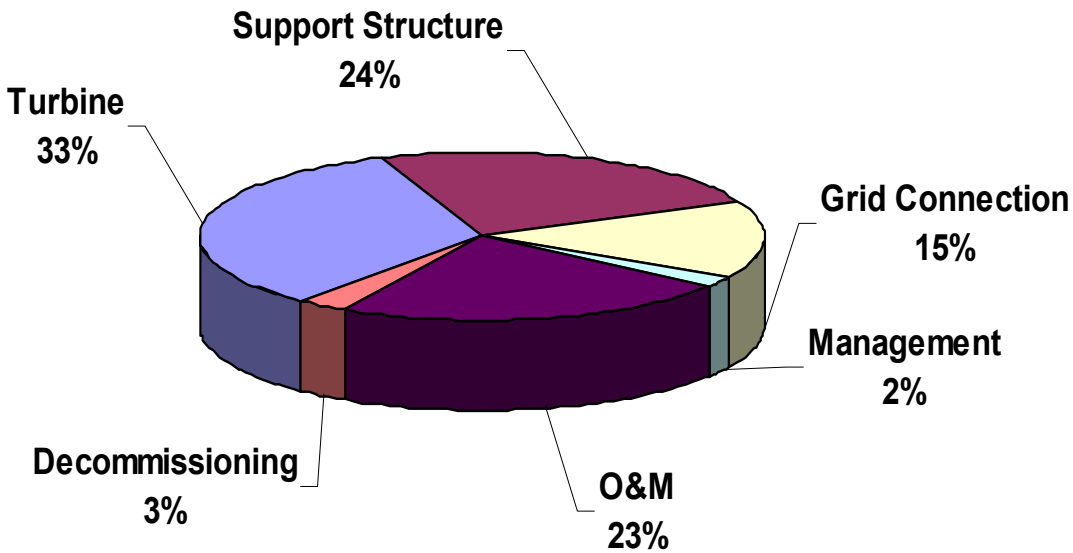
2014: 5 cents/kWh

Evolution of U.S. Commercial Wind Technology



Why Are Offshore Turbines Bigger?

- Turbines are about 1/3 of total project cost offshore.
- Balance of station becomes more significant.
- As turbines grow larger:
  - Support structure costs decrease
  - Electrical infrastructure costs decrease (Grid Connection)
  - Operational expenses (O&M) decrease
  - More energy is generated per area.
- High Capacity offshore infrastructure enables larger machines.



Offshore Wind - Life Cycle Cost of Energy

Photo Credit: GE Energy

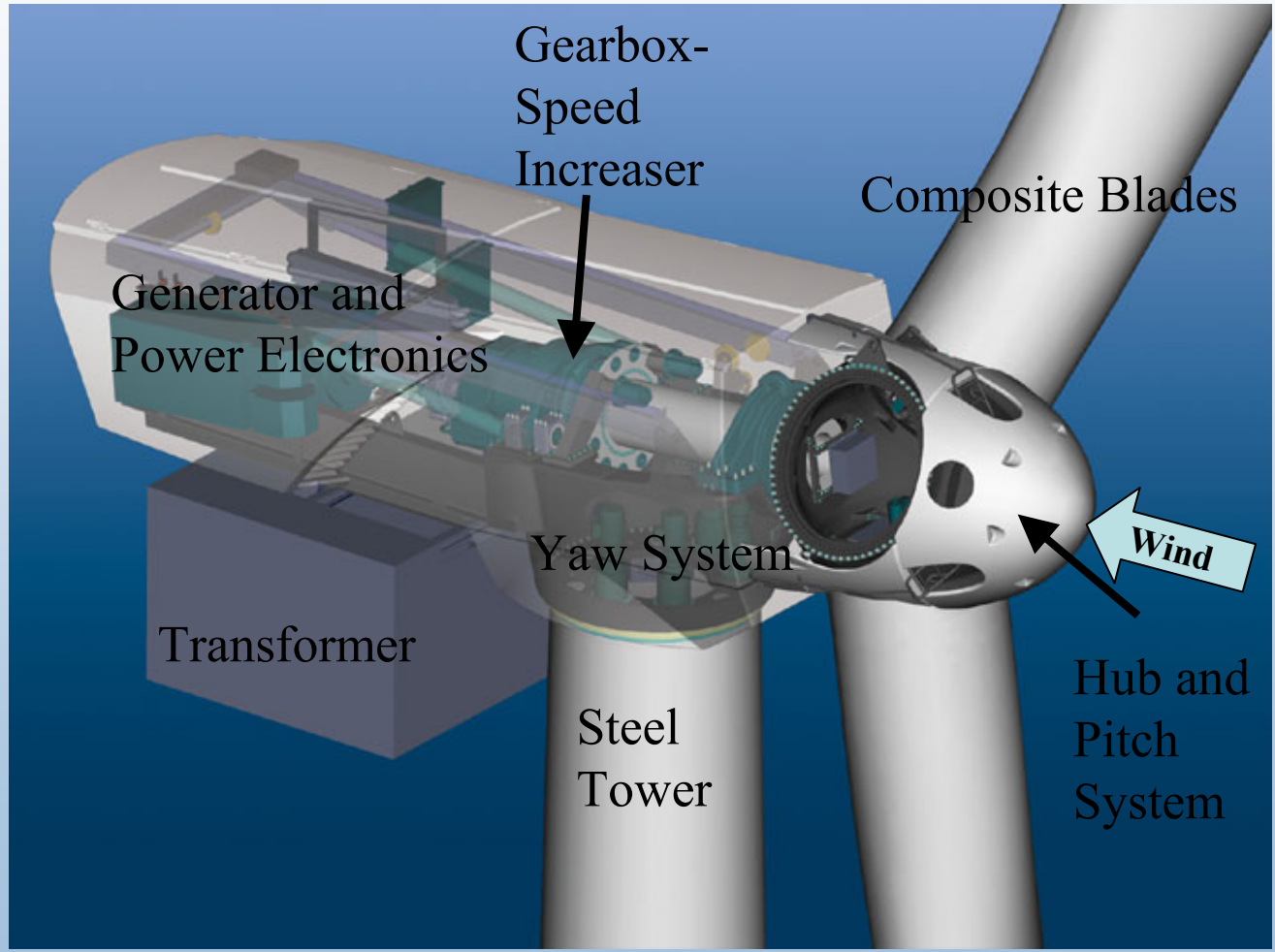
Wind Turbine Anatomy

A Typical Large Turbine has Multiple Subsystems and Controls

Photo Credit: GE Energy

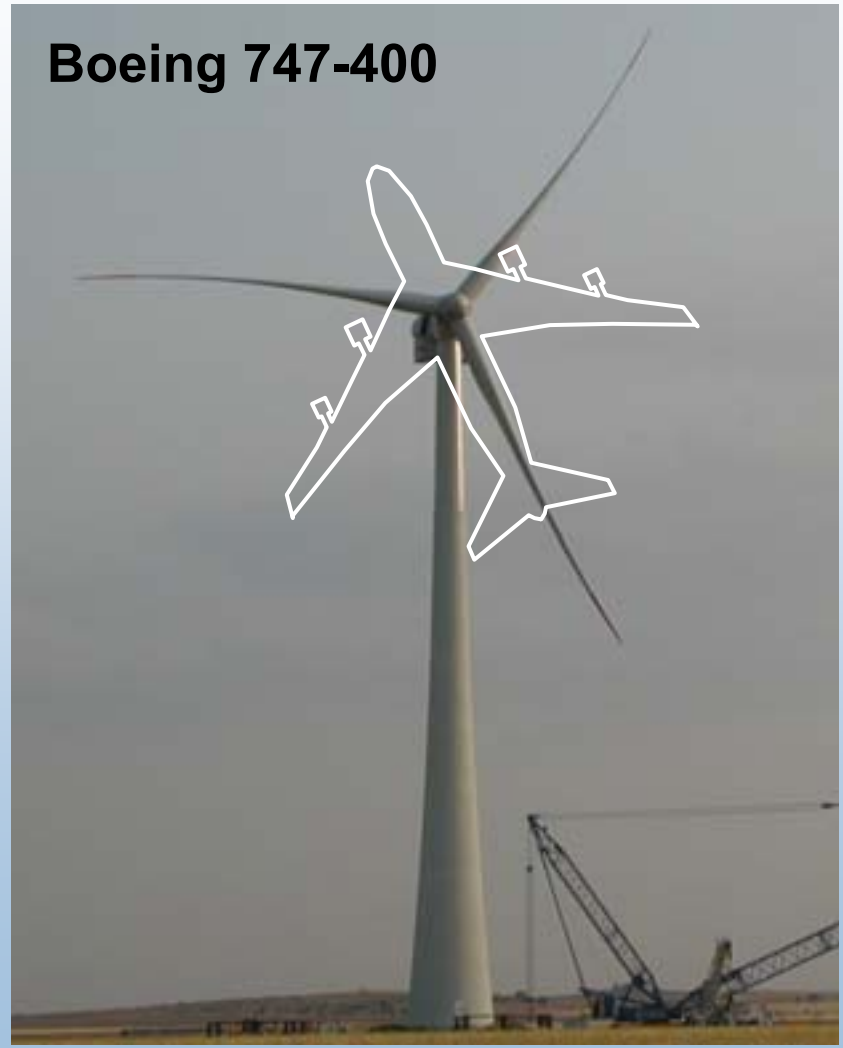
At it's simplest, the wind turns the turbine's blades, which spin a shaft connected to a generator that makes electricity.

Large turbines are grouped together to form a wind power plant, which feeds electricity to the grid.



Offshore GE Wind Energy 3.6 MW Prototype

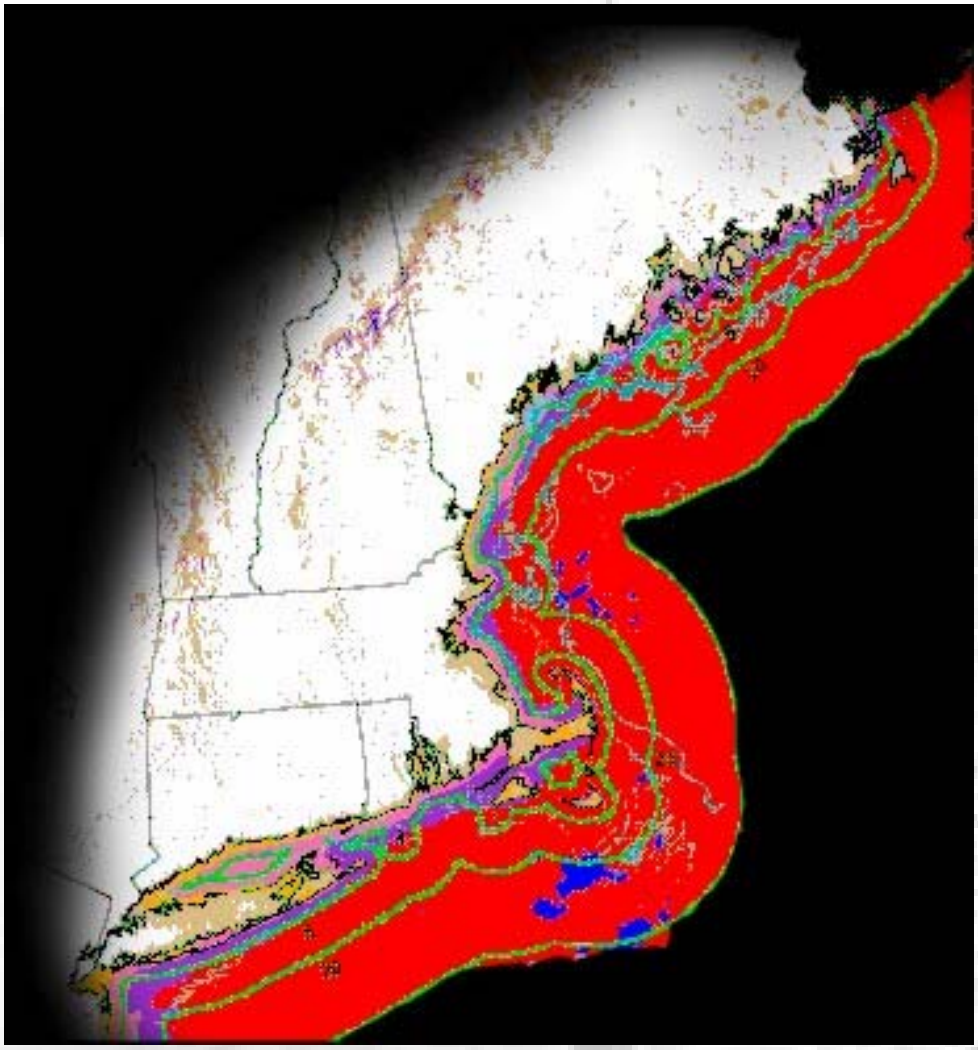
- Offshore GE 3.6 MW
  104 meter rotor diameter
- Offshore design requirements considered from the outset:
  - Crane system for all components
  - Simplified installation
  - Helicopter platform



RePower 5-MW - Worlds Largest Turbine

- 5-MW Rating
- 61.5-m blade length (LM Glasfibres)
- Offshore Demonstration project by Talisman Energy in Beatrice Fields
  - 45-m Water Depths
  - Two machines

US Offshore Wind Resource Assessment



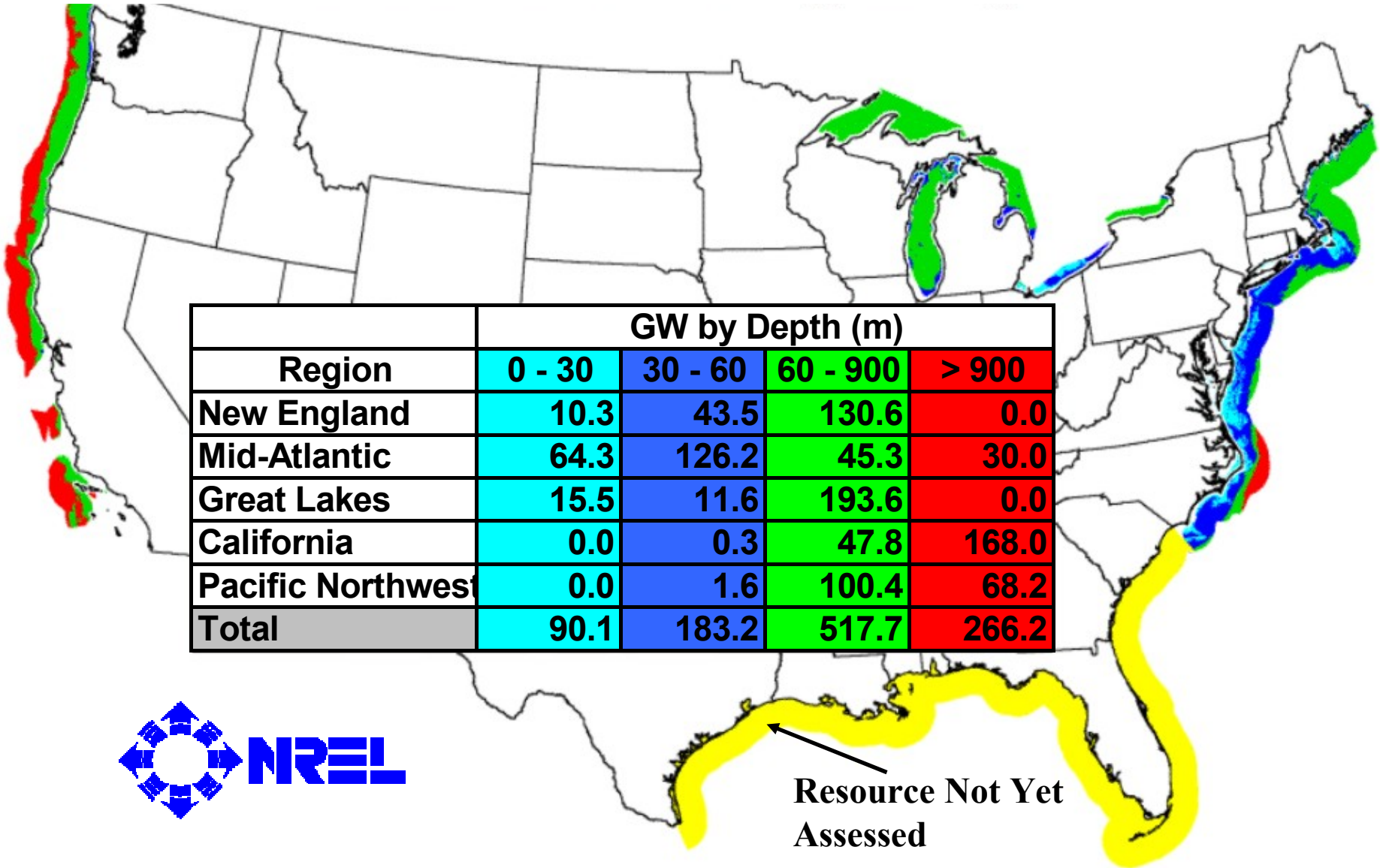
	GW by Depth (m)			
Region	0 - 30	30 - 60	60 - 900	> 900
New England	10.3	43.5	130.6	0.0
Mid-Atlantic	64.3	126.2	45.3	30.0
Great Lakes	15.5	11.6	193.6	0.0
California	0.0	0.3	47.8	168.0
Pacific Northwest	0.0	1.6	100.4	68.2
Total	**90.1**	**183.2**	**517.7**	**266.2**

Exclusion Criteria

- **Findings are preliminary**
- **Inside 5nm – 100% exclusion**
- **67% - 5 to 20nm resource exclusion to account for avian, marine mammal, view shed, restricted habitats, shipping routes & other habitats.**
- **33% exclusion– 20 to 50 nm**
- **Total estimated capacity – 908-GW**

(Reference: 2004 total U.S. electrical generation capacity for all fossil, nuclear and renewable generation is 914 GW)

U.S. Offshore Wind Energy Resource



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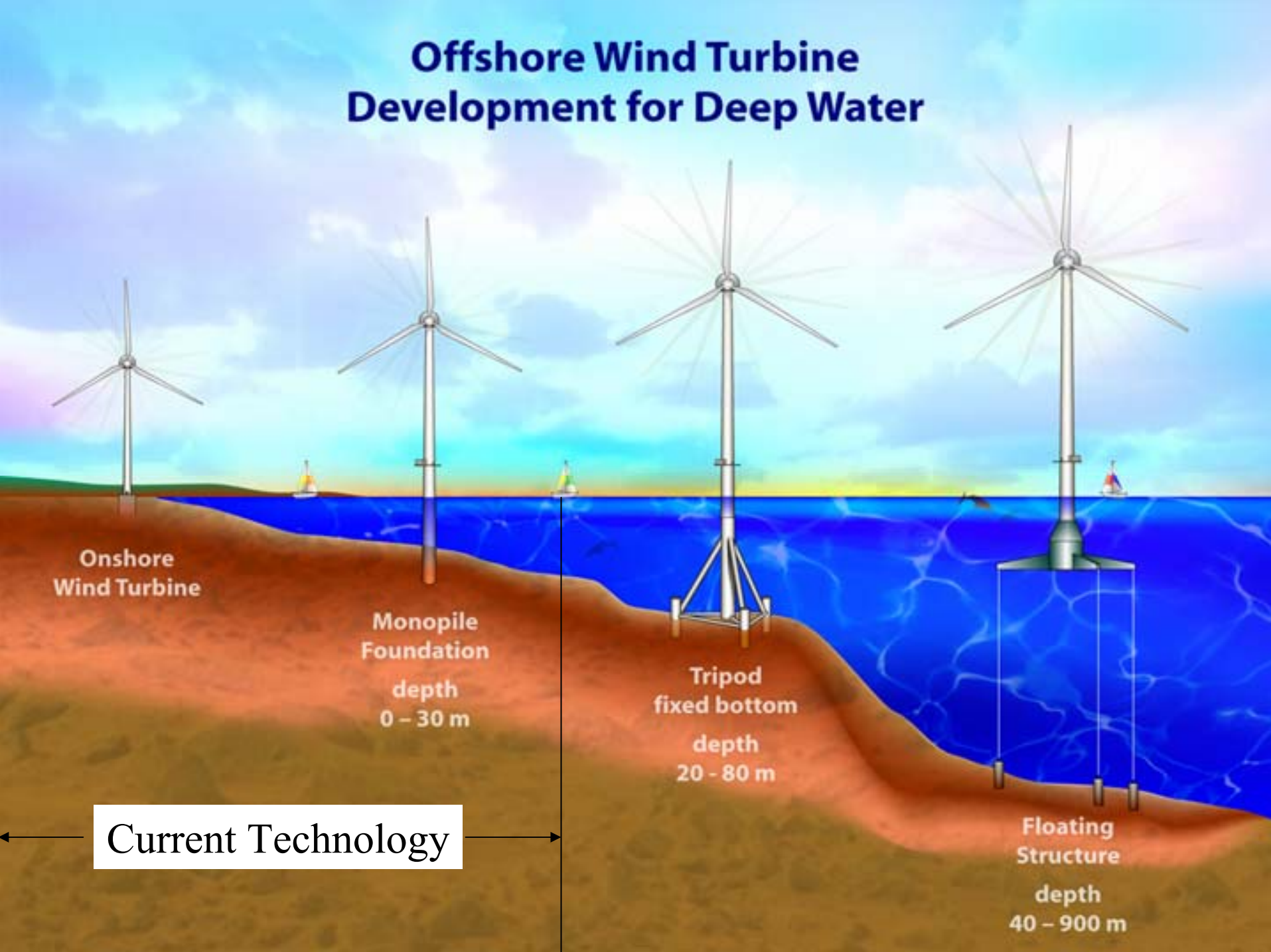
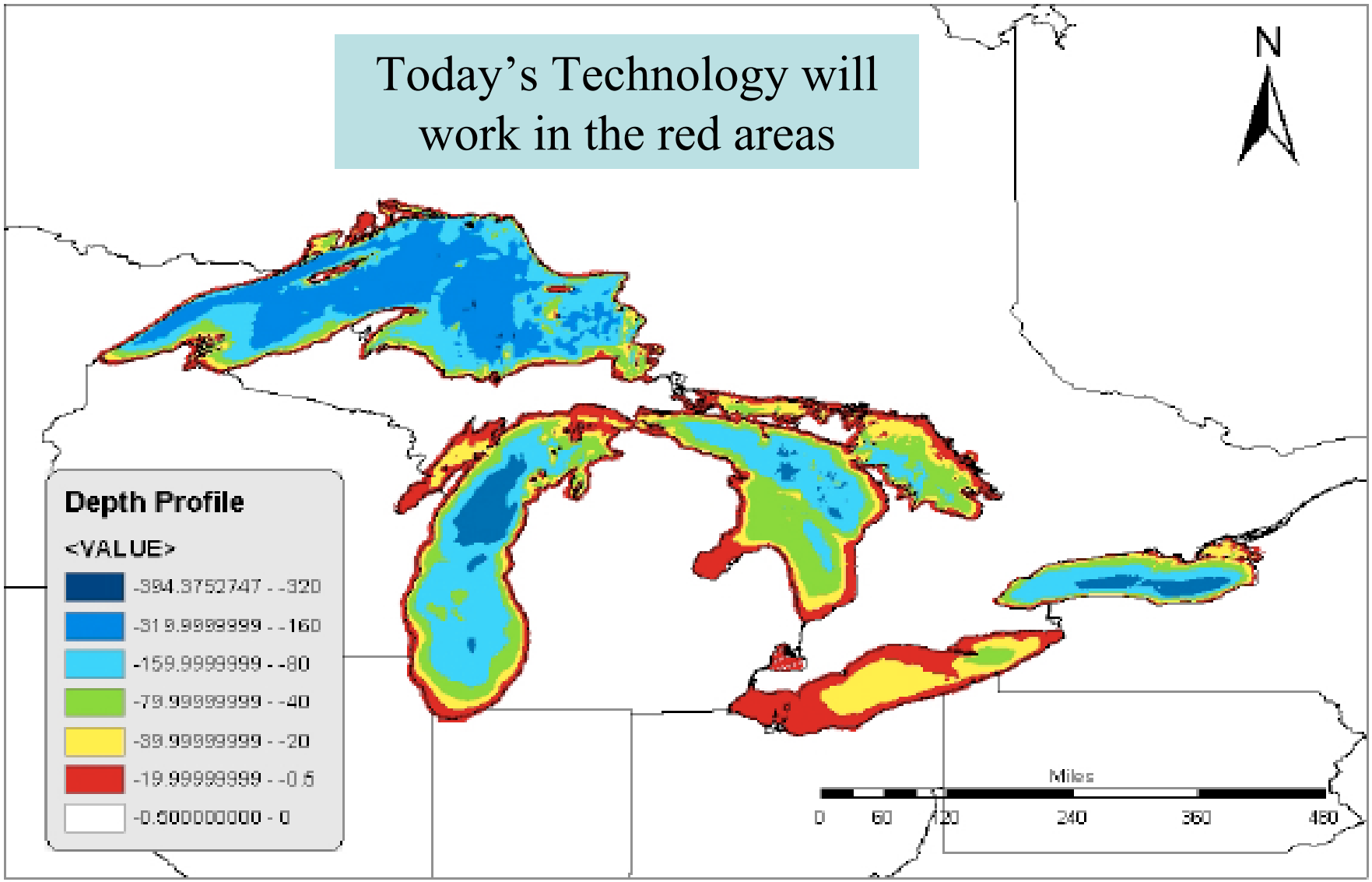
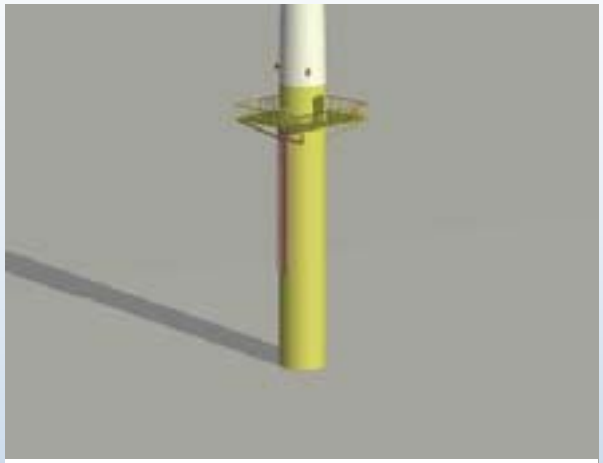

Offshore Wind Turbine
Development for Deep Water
Onshore
Wind Turbine
Monopile
Foundation
depth
0 – 30 m
Tripod
fixed bottom
depth
20 - 80 m
Floating
Structure
depth
40 – 900 m
Current Technology

Great Lakes Bathymetric Map



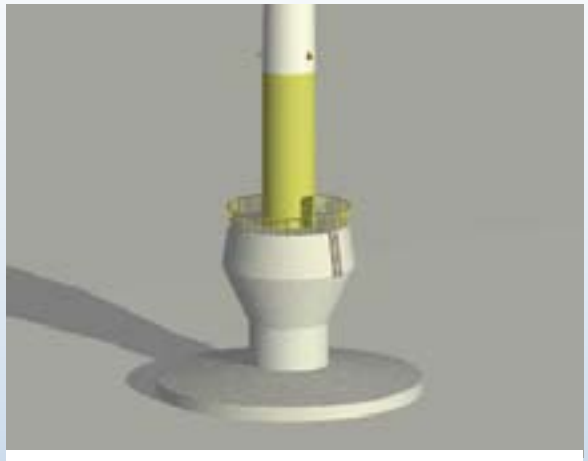
Foundation Types

Proven Designs



Monopile Foundation

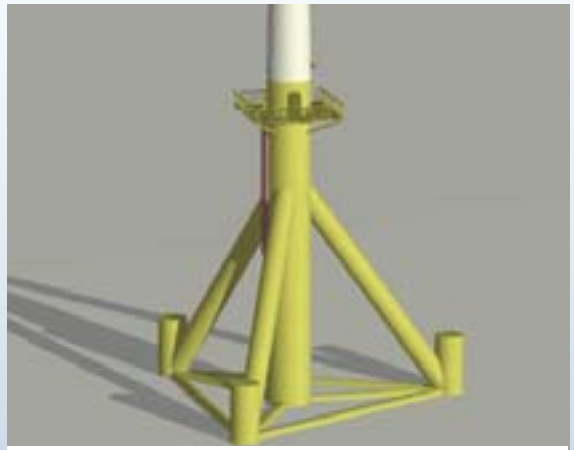
- Most Common Type
- Minimal Footprint
- Depth Limit 25-m
- Low stiffness



Gravity Foundation

- Larger Footprint
- Depth Limit?
- Stiffer but heavy

Future?

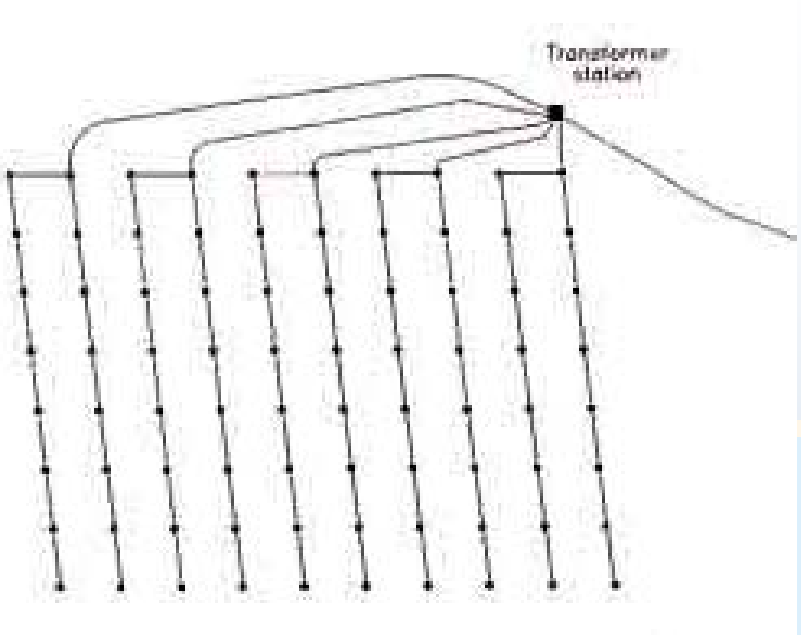


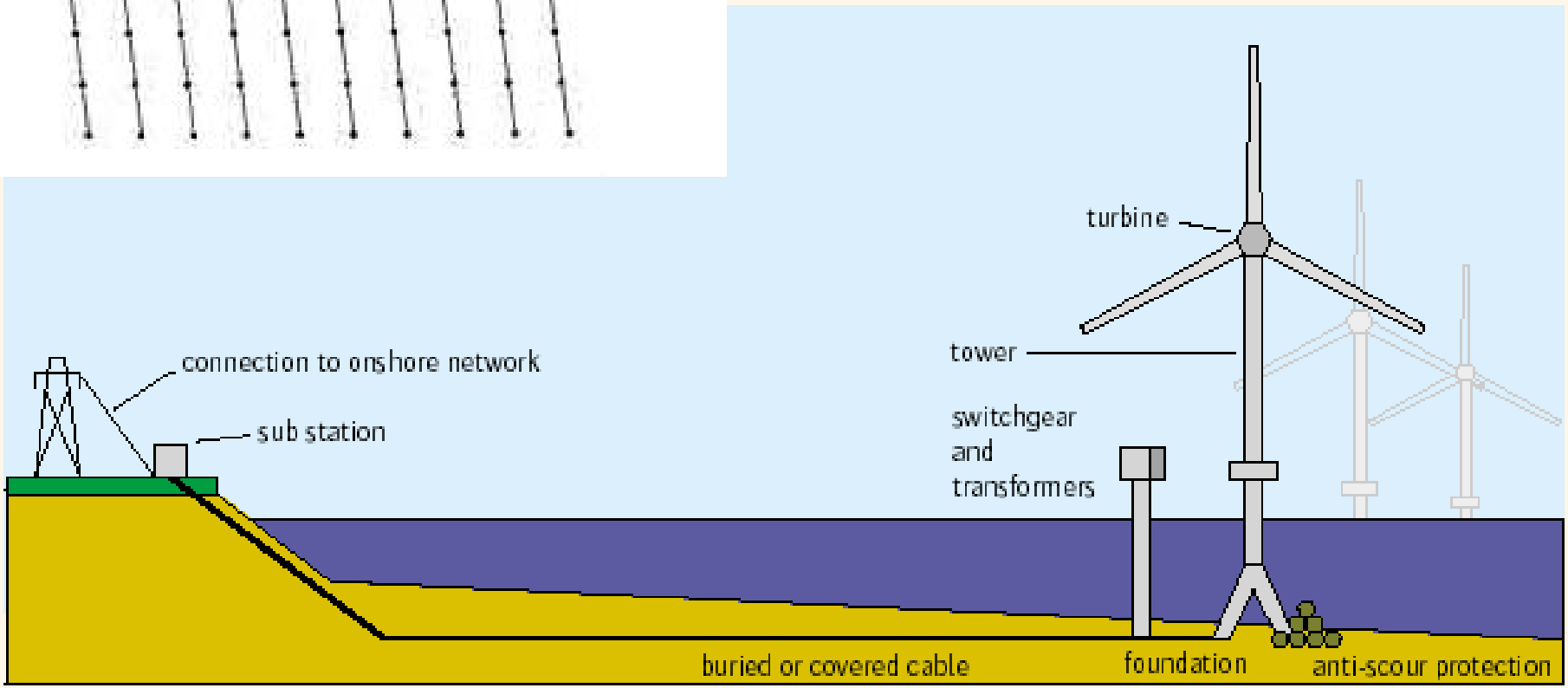
Tripod/Truss Foundation

- No wind experience
- Oil and gas to 450-m
- Larger footprint

Graphics source: http://www.offshorewindenergy.org/

Typical Offshore Wind Farm Layout





Horns Rev Wind Power Plant - Denmark

Country: Denmark
Location: West Coast
Total Capacity: 160 MW
Number of Turbines: 80
Distance to Shore: 14-20 km
Depth: 6-12 m
Capital Costs: 270 million Euro
Manufacturer: Vestas
Total Capacity: 2 MW
Turbine-type: V80 - 80m diameter
Hub-height: 70-m
Mean Windspeed: 9.7 m/s
Annual Energy output: 600 GWh

Ice Floe in Baltic Sea

Credit: Wind Power Monthly Cover Photo
Feb 2003

A Future Vision for Wind Energy Markets

Today 2005

Bulk Power Generator
4-6¢ at 15mph

- Land Based
- Bulk Electricity
- Wind Farms

Potential 20% of Electricity Market

Tomorrow

Land Based Electricity Path

Land Based LWST Large-Scale 2–5 MW

Transmission Barriers

LWST Turbines:
- 3¢/kWh at 13mph
- Electricity Market

2012

Offshore Electricity Path

Offshore Turbines 5 MW and Larger

Cost & Regulatory Barriers

Offshore LWST Turbine:
- 5 cents/kWh
- Shallow/***Deep*** *water*
- Electricity Market
- Higher wind Sites

2014 and Beyond

Advanced Applications Path

Land or Sea Based:
- **Hydrogen**
- **Clean Water**

Cost & Infrastructure Barriers

Custom Turbines:
- Electricity
- H2 production
- Desalinate water
- Storage
- Multi-Market

2030 and Beyond